RECOMBINANT ANTI-TUMOR RNASE

CROSS REFERENCE TO RELATED APPLICATIONS

Not applicable.

FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

Not applicable.

BACKGROUND OF THE INVENTION

Ribonucleases such as ribonuclease A ("RNase A") and their cytotoxicity towards tumor cells were discovered in the 1960s (reviewed in Roth, J., *Cancer Res.* **23**:657-666 (1963)). In the 1970s, human serum was also discovered to contain several RNAses that are expressed in a tissue specific manner (Reddi, E., *Biochem. Biophys. Res. Commun.* **67**:110-118 (1975); and Blank, *et al.*, HUMAN BODY FLUID RIBONUCLEASES: DETECTION, INTERRELATIONSHIPS AND SIGNIFICANCE, pp203-209 (IRL Press, London, 1981)).

Further to these early studies was the discovery that an anti-tumor protein from oocytes of *Rana pipiens* had homology to RNAse A (Ardelt, *et al.*, *J. Biol. Chem.* **256**:245-251(1991)). This protein was termed ONCONASE®, Alfacell Corporation, N.J. See also *e.g.*, Darzynkiewicz, *et al.*, *Cell Tissue Kinet.* **21**:169-182 (1988); Mikulski, *et al.*, *Cell Tissue Kinet.* **23**:237-246 (1990); and U.S. Patent No. 4,888,172).

Phase I and Phase I/II clinical trials of ONCONASE® as a single therapeutic agent in patients with a variety of solid tumors (Mikulski, *et al.*, *Int. J. of Oncology* **3**: 57-64 (1993)) or combined with tamoxifen in patients with advanced pancreatic carcinoma have been completed (Chun, *et al.*, *Proc. Amer. Soc. Clin. Oncol.* **14**:210 (1995)) and the protein has been found to be efficacious in pancreatic, renal cell, and prostate cancers as well as mesothelioma.

Conjugation of ONCONASE® to cell-type-specific ligands was found to increase its potency towards tumor cells (Rybak, *et al.*, *Drug Delivery* **1**:3-10 (1993)).

Taken together, these results indicated that ONCONASE® has properties advantageous to the generation of a potent selective cell killing agent.

Development of Onconase® conjugates for human therapeutics has been slow. Onconase® is derived from amphibian tissue and trace contaminants present in the purified preparation stimulate undesirable immune responses in humans. This side-effect has led to production of a recombinant form of the protein (Newton, *et al., Protein Engineering* **10**:463-470 (1997) and PCT published application WO 97/38112).

However, expression of active recombinant Onconase® has been problematic. Onconase® requires a pyroglutamic acid at the N-terminus for activity. Unfortunately, Onconase® with a N-terminal glutamine is not expressed by bacteria but accumulates in insoluble inclusion bodies. To increase bacterial expression of soluble Onconase®, methionine has been appended to the N-terminus. However, this modification of the protein prevents the formation of the pyroglutamic acid necessary for activity. Therefore, it has been necessary to engineer Onconase® with an N-terminal methionine only to remove it for activity. The cleaved and the uncleaved proteins must then be separated to obtain a pure composition of high purity and activity.

Other problems have arisin in the manufacture of Onconase®-based fusion proteins. It has been difficult to fuse recombinant Onconase® in frame to ligand binding moieties and retain proper folding of both the Onconase® and the ligand binding moiety. This has limited the use of Onconase® in targeted cell killing to only those compounds that can be chemically conjugated.

Thus, there exists in the art a need for recombinant ribonucleases that can be expressed in bacteria and retain activity. Furthermore, there exists a need for a ribonuclease with anti-tumor activity that retains its activity when produced as a single chain fusion protein. This invention fulfills these and other needs.

SUMMARY OF THE INVENTION

This invention provides for new recombinant ribonuclease proteins. The proteins, unlike Onconase®, are expressed well by bacteria without an N-terminal methionine. This is due largely to the presence of a signal peptide that is cleaved by the bacteria. The ribonucleases are then secreted into the bacterial media. The soluble

expression of these ribonucleases allows the proteins of this invention to be fused in-frame with ligand binding moieties to form cytotoxic fusion proteins.

Specifically, this invention provides for a ribonuclease expressed from recombinant DNA that has (a) measurable ribonuclease activity; (b) an amino terminal end beginning with a glutamine or a glutamine cyclized to a pyroglutamic acid; (c) a leucine at position 11; an asparagine at position 21, a threonine at position 85, and a histidine at position 103, such positions being determined with reference to those specified amino acid positions of SEQ ID NO:2; and (d) is substantially identical to SEQ ID NO:2. In one embodiment, the ribonuclease is expressed with a methionine at the 1 position (SEQ ID NO:6). In another, more preferred embodiment, the ribonuclease is expressed with a methionine at the 1 position and an amino acid change from methionine to leucine at position 24 (SEQ ID NO:8). In the most preferred embodiment, the ribonuclease is expressed with histidine residues at positions 1 to 6, a methionine at 7 and a leucine at position 30 (SEQ ID NO:9). In alternative embodiment of the invention, the glutamine at position 1 is replaced with a serine (SEQ ID NO:11).

In another embodiment relating to SEQ ID NO:2, the ribonuclease is transcribed and translated with a signal peptide (SEQ ID NO:28). Post-translation modification by the expressing cell cleaves the signal peptide from the ribonuclease and the protein is secreted by the host cell.

In another embodiment of the invention, ribonucleases encoded by the nucleic acid sequence of SEQ ID NO:14 and conservative variants thereof are claimed. Within this embodiment are the amino acid sequences of SEQ ID NO:17, SEQ ID NO:19, SEQ ID NO:21, SEQ ID NO:24 and SEQ ID NO:26. This ribonuclease can also be engineered to comprise the signal sequence mentioned above.

Also encompassed within this invention are cytotoxic reagents comprising the ribonucleases with or without the conservative substitutions listed above linked to a ligand binding moiety. In one embodiment, the linkage is through a covalent bond. In a preferred embodiment, the covalent bond is at the carboxy terminus of the ribonuclease.

In one aspect of this embodiment, the ribonucleases of this invention are linked to hCG. This has been found to be efficaceous against Kaposi's Sarcoma cells.

In another aspect of this embodiment, the ligand binding moiety is an antibody directed against a cell surface antigen present on a cancer cell. In a preferred

aspect, the antibody is a recombinant single chain antibody directed against a cell surface antigen on a cancerous B cell, in particular, CD22. In a most preferred aspect, the ligand binding moiety is LL2.

In yet another embodiment, a method is provided which prepares a substantially pure ribonuclease of this invention. In addition, the method can be used to purify a cytotoxic reagent of this invention. The method comprises: (i) contacting a ribonuclease with an $(His)_6$ histidine tag and a methionine at position 7 with an effective concentration of a cleaving agent such that the ribonuclease is cleaved after the carboxy group of methionine at position 1; (ii) passing the ribonuclease through a Ni^{2+}-NTA agarose column; and (iii) eluting the substantially pure ribonuclease from the column. In a preferred embodiment, the cleaving agent is CNBr.

In still another embodiment of this invention, pharmaceutical compositions are provided which comprise a ribonuclease expressed from recombinant DNA. The ribonucleases are selected from the group consisting of SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:11, SEQ ID NO:13, SEQ ID NO:15, SEQ ID NO:17, SEQ ID NO:19, SEQ ID NO:21, SEQ ID NO:24 and SEQ ID NO:26 in a pharmaceutically acceptable carrier. In one aspect of this embodiment, the pharmaceutical composition also contains an antineoplast, preferably Adriamycin.

In another embodiment, pharmaceutical compositions are provided which comprise the ribonucleases of this invention linked to a ligand binding moiety. As above, the pharmaceutical composition may contain an antineoplast, preferably Adriamycin.

In yet another embodiment of this invention, a method is provided for killing cancer cells. The method comprises contacting cells to be killed with a ribonuclease expressed by recombinant DNA and having a sequence selected from the group consisting of SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:11, SEQ ID NO:13, SEQ ID NO:15, SEQ ID NO:17, SEQ ID NO:19, SEQ ID NO:21, SEQ ID NO:24 and SEQ ID NO:26. In addition, the method also comprises contacting cells to be killed with a cytotoxic reagent comprising the ribonucleases listed above linked to a ligand binding moiety. In a preferred embodiment, the cancer cell to be killed is a malignant B cell and the ligand binding moiety is an antibody. In a preferred aspect, the antibody is a single chain antibody directed against CD22. In a most preferred embodiment, the antibody is LL2.

DETAILED DESCRIPTION OF THE INVENTION

I. Definitions

Unless defined otherwise herein, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Singleton, *et al.*, DICTIONARY OF MICROBIOLOGY AND MOLECULAR BIOLOGY, 2D ED., John Wiley and Sons, New York (1994), and Hale & Marham, THE HARPER COLLINS DICTIONARY OF BIOLOGY, Harper Perennial, NY (1991) provide one of skill with a general dictionary of many of the terms used in this invention. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, the preferred methods and materials are described. Numeric ranges are inclusive of the numbers defining the range. Unless otherwise indicated, nucleic acids are written left to right in 5' to 3' orientation; amino acid sequences are written left to right in amino to carboxy orientation, respectively. The headings provided herein are not limitations of the various aspects or embodiments of the invention which can be had by reference to the specification as a whole. Accordingly, the terms defined immediately below are more fully defined by reference to the specification as a whole.

The terms "isolated," "purified" or "biologically pure" refer to material that is substantially or essentially free from components which normally accompany it as found in its native state. Purity and homogeneity are typically determined using analytical chemistry techniques such as polyacrylamide gel electrophoresis or high performance liquid chromatography. A protein that is the predominant species present in a preparation is substantially purified. In particular, an isolated ribonuclease nucleic acid is separated from open reading frames that flank the ribonuclease gene and encode proteins other than ribonuclease. The term "purified" denotes that a nucleic acid or protein gives rise to essentially one band in an electrophoretic gel. Particularly, it means that the nucleic acid or protein is at least 85% pure, more preferably at least 95% pure, and most preferably at least 99% pure.

"Nucleic acid" refers to deoxyribonucleotides or ribonucleotides and polymers thereof in either single- or double-stranded form. Unless specifically limited, the term encompasses nucleic acids containing known analogs of natural nucleotides, which have similar binding properties as the reference nucleic acid and are metabolized in a

manner similar to naturally occurring nucleotides. Unless otherwise indicated, a particular nucleic acid sequence also implicitly encompasses conservatively modified variants thereof (*e.g.*, degenerate codon substitutions) and complementary sequences, as well as the sequence explicitly indicated. Specifically, degenerate codon substitutions may be achieved by generating sequences in which the third position of one or more selected (or all) codons is substituted with mixed-base and/or deoxyinosine residues (Batzer, *et al.*, *Nucleic Acid Res.* **19**:5081 (1991); Ohtsuka, *et al.*, *J. Biol. Chem.* **260**:2605-2608 (1985); and Rossolini, *et al.*, *Mol. Cell. Probes* **8**:91-98 (1994)). The term nucleic acid is used interchangeably with gene, cDNA, and mRNA encoded by a gene.

The terms "polypeptide," "peptide" and "protein" are used interchangeably herein to refer to a polymer of amino acid residues. The terms apply to amino acid polymers in which one or more amino acid residue is an artificial chemical analog of a corresponding naturally occurring amino acid, as well as to naturally occurring amino acid polymers.

Amino acids may be referred to herein by either their commonly known three letter symbols or by the one-letter symbols recommended by the IUPAC-IUB Biochemical Nomenclature Commission. Nucleotides, likewise, may be referred to by their commonly accepted single-letter codes.

"Conservatively modified variants" applies to both amino acid and nucleic acid sequences. With respect to particular nucleic acid sequences, conservatively modified variants refers to those nucleic acids which encode identical or essentially identical amino acid sequences, or where the nucleic acid does not encode an amino acid sequence, to essentially identical sequences. Because of the degeneracy of the genetic code, a large number of functionally identical nucleic acids encode any given protein. For instance, the codons GCA, GCC, GCG and GCU all encode the amino acid alanine. Thus, at every position where an alanine is specified by a codon, the codon can be altered to any of the corresponding codons described without altering the encoded polypeptide. Such nucleic acid variations are "silent variations," which are one species of conservatively modified variations. Every nucleic acid sequence herein which encodes a polypeptide also describes every possible silent variation of the nucleic acid. One of skill will recognize that each codon in a nucleic acid (except AUG, which is ordinarily the only codon for methionine) can be modified to yield a functionally identical molecule. Accordingly, each silent

variation of a nucleic acid which encodes a polypeptide is implicit in each described sequence.

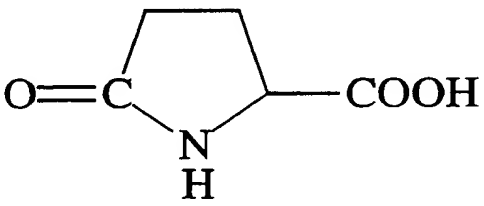
As to amino acid sequences, one of skill will recognize that individual substitutions, deletions or additions to a nucleic acid, peptide, polypeptide, or protein sequence which alters, adds or deletes a single amino acid or a small percentage of amino acids in the encoded sequence is a "conservatively modified variant" where the alteration results in the substitution of an amino acid with a chemically similar amino acid. Conservative substitution tables providing functionally similar amino acids are well known in the art.

The following six groups each contain amino acids that are conservative substitutions for one another:

1) Alanine (A), Serine (S), Threonine (T);
2) Aspartic acid (D), Glutamic acid (E);
3) Asparagine (N), Glutamine (Q);
4) Arginine (R), Lysine (K);
5) Isoleucine (I), Leucine (L), Methionine (M), Valine (V); and
6) Phenylalanine (F), Tyrosine (Y), Tryptophan (W).

(*see, e.g.*, Creighton, *Proteins* (1984)).

"Pyroglutamic acid" is the cyclized internal amide of L-glutamic acid with the following structure:



As used herein a "nucleic acid probe or oligonucleotide" is defined as a nucleic acid capable of binding to a target nucleic acid of complementary sequence through one or more types of chemical bonds, usually through complementary base pairing, usually through hydrogen bond formation. As used herein, a probe may include natural (*i.e.*, A, G, C, or T) or modified bases (7-deazaguanosine, inosine, *etc.*). In addition, the bases in a probe may be joined by a linkage other than a phosphodiester

bond, so long as it does not interfere with hybridization. Thus, for example, probes may be peptide nucleic acids in which the constituent bases are joined by peptide bonds rather than phosphodiester linkages. It will be understood by one of skill in the art that probes may bind target sequences lacking complete complementarity with the probe sequence depending upon the stringency of the hybridization conditions. The probes are preferably directly labeled as with isotopes, chromophores, lumiphores, chromogens, or indirectly labeled such as with biotin to which a streptavidin complex may later bind. By assaying for the presence or absence of the probe, one can detect the presence or absence of the select sequence or subsequence.

A "labeled nucleic acid probe or oligonucleotide" is one that is bound, either covalently, through a linker, or through ionic, van der Waals or hydrogen bonds to a label such that the presence of the probe may be detected by detecting the presence of the label bound to the probe.

"Amplification" primers are oligonucleotides comprising either natural or analog nucleotides that can serve as the basis for the amplification of a select nucleic acid sequence. They include, *e.g.,* polymerase chain reaction primers and ligase chain reaction oligonucleotides.

The term "recombinant" when used with reference, *e.g.,* to a cell, or nucleic acid, or vector, indicates that the cell, or nucleic acid, or vector, has been modified by the introduction of a heterologous nucleic acid or the alteration of a native nucleic acid, or that the cell is derived from a cell so modified. Thus, for example, recombinant cells express genes that are not found within the native (non-recombinant) form of the cell or express native genes that are otherwise abnormally expressed, under expressed or not expressed at all.

The term "identical" in the context of two nucleic acids or polypeptide sequences refers to the residues in the two sequences that are the same when aligned for maximum correspondence, as measured using one of the following "sequence comparison algorithms."

One example of a useful algorithm is PILEUP. PILEUP creates a multiple sequence alignment from a group of related sequences using progressive, pairwise alignments. It can also plot a tree showing the clustering relationships used to create the alignment. PILEUP uses a simplification of the progressive alignment method of Feng &

Doolittle, *J. Mol. Evol.* **35**:351-360 (1987). The method used is similar to the method described by Higgins & Sharp, *CABIOS* **5**:151-153 (1989). The program can align up to 300 sequences of a maximum length of 5,000. The multiple alignment procedure begins with the pairwise alignment of the two most similar sequences, producing a cluster of two aligned sequences. This cluster can then be aligned to the next most related sequence or cluster of aligned sequences. Two clusters of sequences can be aligned by a simple extension of the pairwise alignment of two individual sequences. The final alignment is achieved by a series of progressive, pairwise alignments. The program can also be used to plot a dendrogram or tree representation of clustering relationships. The program is run by designating specific sequences and their amino acid or nucleotide coordinates for regions of sequence comparison. Another example of an algorithm that is suitable for determining sequence similarity is the BLAST algorithm, which is described in Altschul, *et al., J. Mol. Biol.* **215**:403-410 (1990). Software for performing BLAST analyses is publicly available through the National Center for Biotechnology Information (http://www.ncbi.nlm.nih.gov/). This algorithm involves first identifying high scoring sequence pairs (HSPs) by identifying short words of length W in the query sequence that either match or satisfy some positive-valued threshold score T when aligned with a word of the same length in a database sequence. T is referred to as the neighborhood word score threshold (Altschul, *et al*, *supra*). These initial neighborhood word hits act as seeds for initiating searches to find longer HSPs containing them. The word hits are extended in both directions along each sequence for as far as the cumulative alignment score can be increased. Extension of the word hits in each direction are halted when: the cumulative alignment score falls off by the quantity X from its maximum achieved value; the cumulative score goes to zero or below, due to the accumulation of one or more negative-scoring residue alignments; or the end of either sequence is reached. The BLAST algorithm parameters W, T, and X determine the sensitivity and speed of the alignment. The BLAST program uses as defaults a wordlength (W) of 11, the BLOSUM62 scoring matrix (*see* Henikoff & Henikoff, *Proc. Natl. Acad. Sci. USA* **89**:10915 (1989)) alignments (B) of 50, expectation (E) of 10, M=5, N=-4, and a comparison of both strands.

The BLAST algorithm performs a statistical analysis of the similarity between two sequences (*see, e.g.*, Karlin & Altschul, *Proc. Nat'l. Acad. Sci. USA* **90**:5873-5787 (1993)). One measure of similarity provided by the BLAST algorithm is

the smallest sum probability (P(N)), which provides an indication of the probability by which a match between two nucleotide or amino acid sequences would occur by chance. For example, a nucleic acid is considered similar to an ribonuclease nucleic acid if the smallest sum probability in a comparison of the test nucleic acid to an ribonuclease nucleic acid is less than about 0.1, more preferably less than about 0.01, and most preferably less than about 0.001. Where the test nucleic acid encodes a ribonuclease polypeptide, it is considered similar to a specified ribonuclease nucleic acid if the comparison results in a smallest sum probability of less than about 0.5, and more preferably less than about 0.2.

The phrase "substantially identical" in the context of two nucleic acids or polypeptides thus typically means that a polynucleotide or polypeptide comprises a sequence that has at least 60% sequence identity, preferably at least 80%, more preferably at least 90% and most preferably at least 95%, compared to a reference sequence using the local homology algorithm of Smith & Waterman, *Adv. Appl. Math.* **2**:482 (1981), by the homology alignment algorithm of Needleman & Wunsch, *J. Mol. Biol.* **48**:443 (1970), by the search for similarity method of Pearson & Lipman, *Proc. Nat'l. Acad. Sci. USA* **85**:2444 (1988), by computerized implementations of these algorithms (GAP, BESTFIT, FASTA, and TFASTA in the Wisconsin Genetics Software Package, Genetics Computer Group, 575 Science Dr., Madison, WI), or by inspection. One indication that two nucleic acid sequences or polypeptide are substantially identical is that the polypeptide which the first nucleic acid encodes is immunologically cross reactive with the polypeptide encoded by the second nucleic acid. Thus, a polypeptide is substantially identical to a second polypeptide, for example, where the two peptides differ only by a conservative substitution. Another indication that two nucleic acid sequences are substantially identical is that the two molecules hybridize to each other under stringent conditions.

The phrase "determined with reference to" in the context of identifying changes in amino acid sequence means that the amino acid as indicated in the sequence listing at that position is changed to the amino acid indicated. For example, in some embodiments of this invention the methionine corresponding to position 23 of SEQ ID NO:2 is changed to a leucine. In SEQ ID NO:2, a methionine is at position 23. In SEQ ID NO:8, the methionine at position 23 in SEQ ID NO:2 corresponds to a methionine at position 24 which has been changed to a leucine.

The phrase "selectively hybridizes to" refers to the binding, duplexing, or hybridizing of a molecule only to a particular nucleotide sequence under stringent hybridization conditions when that sequence is present in a complex mixture (*e.g.*, total cellular) DNA or RNA. The phrase "stringent hybridization conditions" refers to conditions under which a probe will hybridize to its target subsequence, but to no other sequences. Stringent conditions are sequence-dependent and will be different in different circumstances. Longer sequences hybridize specifically at higher temperatures. An extensive guide to the hybridization of nucleic acids is found in Tijssen, TECHNIQUES IN BIOCHEMISTRY AND MOLECULAR BIOLOGY--HYBRIDIZATION WITH NUCLEIC PROBES, "Overview of principles of hybridization and the strategy of nucleic acid assays" (1993). Generally, stringent conditions are selected to be about 5-10°C lower than the thermal melting point (T_m) for the specific sequence at a defined ionic strength pH. The T_m is the temperature (under defined ionic strength, pH, and nucleic concentration) at which 50% of the probes complementary to the target hybridize to the target sequence at equilibrium (as the target sequences are present in excess, at T_m, 50% of the probes are occupied at equilibrium). Stringent conditions will be those in which the salt concentration is less than about 1.0 sodium ion, typically about 0.01 to 1.0 M sodium ion concentration (or other salts) at pH 7.0 to 8.3 and the temperature is at least about 30°C for short probes (*e.g.*, 10 to 50 nucleotides) and at least about 60°C for long probes (e.g., greater than 50 nucleotides). Stringent conditions may also be achieved with the addition of destabilizing agents as formamide.

"Antibody" refers to a polypeptide substantially encoded by an immunoglobulin gene or immunoglobulin genes, or fragments thereof which specifically bind and recognize an antigen. The recognized immunoglobulin genes include the kappa, lambda, alpha, gamma, delta, epsilon and mu constant region genes, as well as the myriad immunoglobulin variable region genes. Light chains are classified as either kappa or lambda. Heavy chains are classified as gamma, mu, alpha, delta, or epsilon, which in turn define the immunoglobulin classes, IgG, IgM, IgA, IgD and IgE, respectively.

An exemplary immunoglobulin (antibody) structural unit comprises a tetramer. Each tetramer is composed of two identical pairs of polypeptide chains, each pair having one "light" (about 25 kDa) and one "heavy" chain (about 50-70 kDa). The N-terminus of each chain defines a variable region of about 100 to 110 or more amino

acids primarily responsible for antigen recognition. The terms variable light chain (V_L) and variable heavy chain (V_H) refer to these light and heavy chains respectively.

Antibodies exist, *e.g.*, as intact immunoglobulins or as a number of well characterized fragments produced by digestion with various peptidases. Thus, for example, pepsin digests an antibody below the disulfide linkages in the hinge region to produce F(ab)'$_2$, a dimer of Fab which itself is a light chain joined to V_H-C_H1 by a disulfide bond. The F(ab)'$_2$ may be reduced under mild conditions to break the disulfide linkage in the hinge region, thereby converting the F(ab)'$_2$ dimer into an Fab' monomer. The Fab' monomer is essentially an Fab with part of the hinge region (*see,* FUNDAMENTAL IMMUNOLOGY, 3D ED., Paul (ed.) 1993). While various antibody fragments are defined in terms of the digestion of an intact antibody, one of skill will appreciate that such fragments may be synthesized *de novo* either chemically or by using recombinant DNA methodology. Thus, the term antibody, as used herein, also includes antibody fragments either produced by the modification of whole antibodies or those synthesized *de novo* using recombinant DNA methodologies (*e.g.*, single chain Fv).

The phrase "single chain Fv" or "scFv" refers to an antibody in which the heavy chain and the light chain of a traditional two chain antibody have been joined to form one chain. Typically, a linker peptide is inserted between the two chains to allow for proper folding and creation of an active binding site.

The term "linker peptide" includes reference to a peptide within an antibody binding fragment (*e.g.*, Fv fragment) which serves to indirectly bond the variable heavy chain to the variable light chain.

The term "contacting" includes reference to placement in direct physical association. With regards to this invention, the term refers to antibody-antigen binding.

An "anti-ribonuclease" antibody is an antibody or antibody fragment that specifically binds a polypeptide encoded by the ribonuclease gene, cDNA, or a subsequence thereof.

An "immunoconjugate" is an antibody molecule in which (a) the constant region, or a portion thereof, is altered, replaced or exchanged so that the antigen binding site (variable region) is linked to a constant region of a different or altered class, effector function and/or species, or an entirely different molecule which confers new properties to the chimeric antibody, *e.g.*, an enzyme, toxin, hormone, growth factor, drug, *etc.*; or (b)

the variable region, or a portion thereof, is altered, replaced or exchanged with a variable region having a different or altered antigen specificity.

A "fusion protein" or when a molecule is "linked" to another refers to a chimeric molecule formed by the joining of two or more polypeptides through a bond formed one polypeptide and another polypeptide. The bond may be covalent or noncovalent. An example of a covalent bond is the chemical coupling of the two polypeptides to form peptide bond. Examples of non-covalent bond are hydrogen bonds, electrostatic interactions and van der Waal's forces.

If the bond is by a peptide bond, the fusion protein may be expressed as a single polypeptide from a nucleic acid sequence encoding a single contiguous fusion protein. A single chain fusion protein is a fusion protein having a single contiguous polypeptide backbone.

A "ligand" or a "ligand binding moiety", as used herein, refers generally to all molecules capable of specifically delivering a molecule, reacting with or otherwise recognizing or binding to a receptor on a target cell. Specifically, examples of ligands include, but are not limited to, immunoglobulins or binding fragments thereof, lymphokines, cytokines, cell surface antigens such as CD22, CD4 and CD8, solubilized receptor proteins such as soluble CD4, hormones, growth factors such as epidermal growth factor (EGF), and the like which specifically bind desired target cells.

The phrase "specifically (or selectively) binds" to an antibody or "specifically (or selectively) immunoreactive with," when referring to a protein or peptide, refers to a binding reaction that is determinative of the presence of the protein in a heterogeneous population of proteins and other biologics. Thus, under designated immunoassay conditions, the specified antibodies bind to a particular protein at least two times the background and do not substantially bind in a significant amount to other proteins present in the sample. Specific binding to an antibody under such conditions may require an antibody that is selected for its specificity for a particular protein. For example, antibodies raised to ribonuclease with the amino acid sequence encoded in SEQ ID NO:2 can be selected to obtain only those antibodies that are specifically immunoreactive with ribonuclease and not with other proteins, except for polymorphic variants, alleles, and closely related interspecies homologs of ribonuclease. This selection may be achieved by subtracting out antibodies that cross react with molecules such as Onconase®. A variety

of immunoassay formats may be used to select antibodies specifically immunoreactive with a particular protein. For example, solid-phase ELISA immunoassays are routinely used to select antibodies specifically immunoreactive with a protein (*see, e.g.*, Harlow & Lane, ANTIBODIES, A LABORATORY MANUAL (1988), for a description of immunoassay formats and conditions that can be used to determine specific immunoreactivity). Typically a specific or selective reaction will be at least twice background signal or noise and more typically more than 10 to 100 times background.

"Cytotoxicity", as used herein, refers to the inhibition of protein synthesis in human tumor cells, *e.g.*, HS578T (ATCC No. HTB 126) using the protocol described in Rybak, *et al.*, *JNCI* **88**:747-753 (1996). A "cytotoxic reagent" of the present invention will have a relative 50% inhibitory concentration (IC_{50}) at least 50% that of an equimolar amount of the polypeptide of SEQ ID NO:2. More preferably, the relative IC_{50} will be at least 60% or 70% that of the polypeptide of SEQ ID NO:2, and even more preferably, at least 100%.

II. Introduction

This invention provides highly active and cytotoxic ribonuclease molecules which can be used to selectively kill and target cells, particularly tumor cells. In some embodiments the molecules are designed to fold into more cytotoxic molecules and in other embodiments, the molecules are designed for better expression in bacteria.

The ribonucleases of this invention are isolated from members of the genus *Rana*. SEQ ID NO:1 represents the nucleic acid sequence of a RNAse derived from a *Rana pipiens* liver mRNA library. The corresponding amino acid sequence is represented by SEQ ID NO:2 (RaPLR1). SEQ ID NO:6 is the amino acid sequence of RaPLR1 but with a methionine at the 1 position. SEQ ID NO:4 is the amino acid sequence of RaPLR1 but with a leucine at position 23 (instead of a methionine). SEQ ID NO:8 represents the sequence shown in SEQ ID NO:4 but with a methionine at the 1 position. SEQ ID NO:9 represents a protein with the amino acid sequence of SEQ ID NO:8 but with a six histidine residue tag at the amino terminus. SEQ ID NO:11 represents RaPLR1 with a serine at the N-terminus and SEQ ID NO:13 represents RaPLR1 with a serine at the 2 position and a methionine at the 1 position. SEQ ID NO:28 is the amino acid sequence of RaPLR1 with the signal peptide at the N-terminus.

In addition to ribonuclease derived from *Rana pipiens*, this invention also encompasses ribonucleases derived from *Rana catesbeiana* oocytes. Although the amino acid sequence of *Rana catesbeiana* oocyte RNAse (RaCOR1) has been known since 1989 (Nitta, R., *et al., J. Biochem.* **106**:729 (1989); Okabe, Y., *et al., J. Biochem* **109**:786 (1991); Liao, Y, *Nucl., Acids Res.* **20**:1371 (1992); Nitta, K., *et al., Glycobiology* **3**:37 (1993); Liao, Y. & Wang, J., *Eur. J. Biochem.* **222**:215 (1994); Wang, J., *et al., Cell Tissue Res.* **280**:259 (1995); Liao, Y., *et al., Protein Expr. Purif.* **7**:194 (1996); and Inokuchi, N., *et al., Biol. Pharm. Bull.* **20**:471 (1997)), genomic DNA or mRNA which encodes the oocyte RNAse has not been discovered. An object of this invention was to deduce the nucleic acid sequence encoding this RNAse and express the RNAse recombinantly.

SEQ ID NO:14 represents the nucleic acid sequence of RaCOR1 but modified to use the preferred codons for *E. coli*, the expression system exemplified in this invention. SEQ ID NO:15 is the corresponding amino acid sequence. SEQ ID NO:17 is the same amino acid sequence as SEQ ID NO:15 but with a methionine at the 1 position. SEQ ID NO:19 is the amino acid sequence of SEQ ID NO:15 but with leucines substituted for methionines at positions 22 and 57. SEQ ID NO:21 is the same as SEQ ID NO:19 except for a methionine at the 1 position. SEQ ID NO:22 is the same as SEQ ID NO:21 except six histidine residues have been appended to the N-terminus. Finally, SEQ ID NO:24 represents RaCOR1 but with a serine at the N-terminus and SEQ ID NO:26 is the same as SEQ ID NO:24 except a methionine is at the 1 position.

Preferably, the ribonuclease molecules will have an amino terminal end selected from the group consisting of:

Gln-

Met-Gln;

Met-Ser;

Met-Thr;

Tyr; and

Pyroglutamic acid-.

Further, it is preferred that the ribonuclease molecules be modified so that the methionine of amino acid position 23 of SEQ ID NO:2 is deleted or replaced by Leu.

In one embodiment of the invention, the methionines at position 22 and 57 of SEQ ID NO:15 are also replaced by a leucine.

In other alternative embodiments, the ribonuclease molecules will be fused at either the carboxyl or amino end to a ligand binding moiety, such as a single chain Fv which recognizes a cell surface antigen on a tumor cell. Other ligand binding moieties include, but are not limited to, other antibody fragments, receptors, antigens, lectins, cytokines, lipopolysaccharides and any other compound that binds to a cell.

Comparisons of the ribonuclease sequences provided here can be made to described sequences in the pancreatic RNAse A superfamily. Many of such members are known and include, but are not limited to, ONCONASE® (Ardelt, W. *et al.*, *J. Biol. Chem.* **266**:245 (1991)); eosinophil derived neurotoxin (EDN) and human eosinophil cationic protein (ECP) (Rosenberg, *et al.*, *J. Exp. Med.* **170**:163 (1989)); angiogenin (Ang) (Fett, J.W. *et al.*, *Biochemistry* **24**:5480 (1985)); bovine seminal RNase (Preuss, *et al.*, *Nuc. Acids. Res.* **18**:1057 (1990)); and bovine pancreatic RNase (Beintama, *et al.*, *Prog. Biophys. Mol. Biol.* **51**:165 (1988)). Amino acid sequence alignment for such RNAses are set out in Youle, *et al.*, *Crit. Rev. Ther. Drug. Carrier Systems* **10**:1-28 (1993).

III. Numbering of Amino Acid Residues

The amino acid sequence positions described herein, unless otherwise indicated, use as a frame of reference the RNAse sequences of the respective SEQ ID NOS: in the SEQUENCE LISTING. Residue numbers indicate the distance from the amino terminus. The amino acid sequence for SEQ ID NO:2 and for SEQ ID NO:15 are set forth in the SEQUENCE LISTING.

IV. RNAse Proteins

The present invention includes RNAse proteins comprising a polypeptide of SEQ ID NO:2 and 15 and conservative variants thereof. The polypeptides of the present invention (SEQ ID NO:2 and 15 and conservative variants thereof) demonstrate cytotoxic activity, as defined herein. The RNAse proteins of the present invention may be limited to the polypeptides of SEQ ID NO:2 and 15 and conservative variants thereof, or may be inclusive of additional amino acid residues linked via peptide bonds to the carboxy and/or amino termini of the polypeptide. Preferably, the conservative variants of SEQ ID NO:2

and 15 comprise a glutamine residue capable of spontaneous cyclization to pyroglutamic acid at the 1 position.

The RNAse proteins of this invention optionally are translated by the host cell with a signal peptide attached. The signal peptide is shown in SEQ ID NO:28. The presence of this sequence allows the host cell, in particular *E. coli*, to secrete soluble protein. In this configuration, the presence of a N-terminal methionine is not necessary for bacterial expression and the N-terminal residue is a glutamine or pyroglutamic acid. One of skill will recognize that other signal peptides may be appended to the RNAse proteins of this invention. The choice of signal peptide will depend on the expressing cell, the protein being expressed and the preference of the practitioner.

The polypeptide of SEQ ID NO:2 or conservatively modified variants thereof may have a leucine or other hydrophobic residue substituting for the methionine at position 23. The polypeptide of SEQ ID NO:15 or conservatively modified variants thereof may have a leucine or other hydrophobic residue substituting for the methionine at positions 22 and 57. Those of skill will recognize that a polypeptide lacking a methionine is typically not subject to specific cleavage using cyanogen bromide.

Proteins of the present invention can be produced by recombinant expression of a nucleic acid encoding the polypeptide followed by purification using standard techniques. Typically, the RNAse proteins are encoded and expressed as a contiguous chain from a single nucleic acid. The length of the RNAse proteins of the present invention is generally less than about 600 amino acids in length.

Recombinant RNAse proteins can also be synthetically prepared in a wide variety of well-known ways. Polypeptides of relatively short size are typically synthesized in solution or on a solid support in accordance with conventional techniques. *See, e.g.,* Merrifield, *J. Am. Chem. Soc.* **85**:2149-2154 (1963). Recombinantly produced or synthetic polypeptides can be condensed to form peptide bonds with other polypeptides or proteins formed synthetically or by recombinant methods. Various automatic synthesizers and sequencers are commercially available and can be used in accordance with known protocols. *See, e.g.,* Stewart & Young, SOLID PHASE PEPTIDE SYNTHESIS, 2d. ed., Pierce Chemical Co. (1984).

A. *RNAse Proteins Comprising Amino Terminal Methionine*

The present invention also includes RNAse proteins comprising: 1) a polypeptide of SEQ ID NO:2 or SEQ ID NO:15 and conservatively modified variants thereof, and 2) a methionine at position 1 (*see, e.g.,* SEQ ID NO:6 and SEQ ID NO:17). Isolated nucleic acids coding for the RNAse proteins of the present invention are also provided. Preferably, as in SEQ ID NO:2 and 15, the position 1 residues of the polypeptides are glutamines. Various embodiments of the polypeptide of SEQ ID NO:2 and 15 and conservative variants thereof may be employed in this aspect of the invention.

Those of skill will understand that an N-terminal methionine or formylmethionine (collectively, "methionine") is typically required for protein synthesis in a bacterial host cell. The N-terminal methionine may be directly linked to the amino acid of position 1 of the polypeptides of the present invention where position 1 is not methionine via a peptide bond. Alternatively, the methionine is indirectly or directly linked to the amino acid of position 1 of the polypeptides of the present invention via a plurality of peptide bonds from a contiguous chain of amino acid residues. The residues, extending and inclusive of the amino terminal methionine to the amino acid directly linked via a peptide bond to the amino terminal amino acid residue of the polypeptide, constitute an amino terminal peptide. Thus, the amino terminal peptide consists of all amino acid residues linked to position 1 of SEQ ID NO:2 or 15 or conservatively modified variants thereof. The N-terminal peptide is at least one amino acid residue in length (*i.e.,* a methionine residue) or may be 5, 10, 20, 50, 100, 200, 300, 400, or more amino acids in length.

The N-terminal peptide may comprise a signal sequence for transport into various organelles or compartments of the host cell, or for transport into the surrounding media. The N-terminal peptide may also encode sequences which aid in purification such as epitopes which allow purification via immunoaffinity chromatography, *e.g.,* a plurality of histidine residues, or sequences recognized by endoproteases such as Factor Xa. The N-terminal peptide may also recognize extracellular and intracellular targets, such as telomerase.

B. *Making the RNAse Protein*

The present invention is also directed to methods of making the RNAse polypeptides of SEQ ID NO:2, SEQ ID NO:15 and conservative variants thereof. The polypeptides of the SEQ ID NO:2 and 15 and conservative variants thereof may conveniently be assayed for cytotoxicity or anti-viral (*e.g.*, HIV-1) inhibition by methods disclosed herein.

1. Expressing the RNAse Protein

This invention relies on routine techniques in the field of recombinant genetics. Basic texts disclosing the general methods of use in this invention include Sambrook, *et al.*, MOLECULAR CLONING, A LABORATORY MANUAL , 2ND ED. (1989); Kriegler, GENE TRANSFER AND EXPRESSION: A LABORATORY MANUAL (1990); and Ausubel *et al.*, (eds.), CURRENT PROTOCOLS IN MOLECULAR BIOLOGY (1994)).

For nucleic acids, sizes are given in either kilobases (kb) or base pairs (bp). These are estimates derived from agarose or acrylamide gel electrophoresis, from sequenced nucleic acids, or from published DNA sequences. For proteins, sizes are given in kilodaltons (kD) or amino acid residue numbers. Proteins sizes are estimated from gel electrophoresis, from sequenced proteins, from derived amino acid sequences, or from published protein sequences.

Oligonucleotides that are not commercially available can be chemically synthesized according to the solid phase phosphoramidite triester method first described by Beaucage & Caruthers, *Tetrahedron Letts.* **22**:1859-1862 (1981), using an automated synthesizer, as described in Van Devanter, *et al.*, *Nucl. Acids Res.* **12**:6159-6168 (1984). Purification of oligonucleotides is by either native acrylamide gel electrophoresis or by anion-exchange HPLC as described in Pearson & Regnier, *J. Chrom.* **255**:137-149 (1983).

The sequence of the cloned genes and synthetic oligonucleotides can be verified after cloning using, *e.g.*, the chain termination method for sequencing double-stranded templates of Wallace, *et al.*, *Gene* **16**:21-26 (1981).

In one embodiment of the invention, a RNAse of SEQ ID NO:4, 8, 9, 13, 17, 21, 22, 26 and conservative variants thereof wherein the nucleic acids encode an amino terminal methionine, are expressed in a host cell. Various aspects of the polypeptides of the present invention which have been previously described may be utilized in this aspect

of the invention. By "host cell" is meant a cellular recipient, or extract thereof, of an isolated nucleic acid which allows for translation of the nucleic acid and requires an amino terminal methionine for translation of the nucleic acid into its encoded polypeptide. Eukaryotic and prokaryotic host cells may be used such as animal cells, insect cells, bacteria, fungi, and yeasts. Methods for the use of host cells in expressing isolated nucleic acids are well known to those of skill and may be found, for example, in Berger & Kimmel, GUIDE TO MOLECULAR CLONING TECHNIQUES, METHODS IN ENZYMOLOGY VOL. 152, Academic Press, Inc., San Diego, CA (Berger); Sambrook, *et al.*, MOLECULAR CLONING - A LABORATORY MANUAL (2ND ED.) VOL. 1-3 (1989) and CURRENT PROTOCOLS IN MOLECULAR BIOLOGY, F.M. Ausubel *et al.*, eds., Current Protocols, a joint venture between Greene Publishing Associates, Inc. and John Wiley & Sons, Inc., (1997 Supplement) (Ausubel). A variety of host cells and expression vectors are available from commercial vendors, or the American Type Culture Collection (Rockville, MD). Accordingly, this invention also provides for host cells and expression vectors comprising the nucleic acid sequences described herein.

Nucleic acids encoding RNAse proteins can be made using standard recombinant or synthetic techniques. Nucleic acids may be RNA, DNA, or hybrids thereof. Given the polypeptides of the present invention, one of skill can construct a variety of clones containing functionally equivalent nucleic acids, such as nucleic acids which encode the same polypeptide. Cloning methodologies to accomplish these ends, and sequencing methods to verify the sequence of nucleic acids are well known in the art. Examples of appropriate cloning and sequencing techniques, and instructions sufficient to direct persons of skill through many cloning exercises are found in Berger & Kimmel; Sambrook *et al.*; and F.M. Ausubel *et al.* (all supra). Product information from manufacturers of biological reagents and experimental equipment also provide information useful in known biological methods. Such manufacturers include the SIGMA chemical company (Saint Louis, MO), R&D systems (Minneapolis, MN), Pharmacia LKB Biotechnology (Piscataway, NJ), CLONTECH Laboratories, Inc. (Palo Alto, CA), Chem Genes Corp., Aldrich Chemical Company (Milwaukee, WI), Glen Research, Inc., GIBCO BRL Life Technologies, Inc. (Gaithersberg, MD), Fluka Chemica-Biochemika Analytika (Fluka Chemie AG, Buchs, Switzerland), Invitrogen, San Diego, CA, and Applied

Biosystems (Foster City, CA), as well as many other commercial sources known to one of skill.

The nucleic acid compositions of this invention, whether RNA, cDNA, genomic DNA, or a hybrid of the various combinations, are isolated from biological sources or synthesized *in vitro*. Deoxynucleotides may be synthesized chemically according to the solid phase phosphoramidite triester method described by Beaucage & Caruthers, *Tetrahedron Letts.* **22**(20):1859-1862 (1981), *e.g.*, using an automated synthesizer, *e.g.*, as described in Needham-VanDevanter, *et al.*, *Nucleic Acids Res.* **12**:6159-6168 (1984).

In one embodiment of the invention, the amino acid sequence of RaCOR1, which had been previously published, was used to deduce a nucleic acid sequence and, using the preferred codon for the expressing cell, synthesized. For example, the RaCOR1 nucleic acid sequence was prepared from the published amino acid sequence of the native RNAse and the preferred codon usage by *E. coli*.

To generate the full length nucleic acid sequence, overlapping oligonucleotides, representing both the sense and nonsense strands of the gene and usually 40-120 bp in length, were synthesized chemically. These DNA fragments were then annealed, ligated and cloned. For example, from the published amino acid sequence of ribonuclease from *Rana catesbeiana* oocytes, a series of oligonucleotide primers were prepared. These primers (SEQ ID NO:32-41) were used to generate the 5' and 3' ends of ribonuclease. The two regions of nucleic acid were then ligated to form the complete coding sequence. An advantage of this method is that mutations are relatively easy to engineer. To do so, one changes the nucleotides within the synthetic primer to correspond to the codon that translates to the desired amino acid.

One of skill will recognize many other ways of generating alterations or variants of a given nucleic acid sequence. Such well-known methods include site-directed mutagenesis, PCR amplification using degenerate oligonucleotides, exposure of cells containing the nucleic acid to mutagenic agents or radiation, chemical synthesis of a desired oligonucleotide (*e.g.*, in conjunction with ligation and/or cloning to generate large nucleic acids) and other well-known techniques. *See,* Giliman & Smith, *Gene* **8**:81-97 (1979), Roberts, *et al.*, *Nature* **328**:731-734 (1987) and Sambrook, Innis, Ausubel, and Berger (*all supra*).

In another embodiment of the present invention, site directed mutagenesis is used to change an interior methionine to a leucine. The nucleic acid sequence is changed by synthesizing an oligonucleotide primer that contains the mutation. The primer is hybridized to a nucleic acids of SEQ ID NO:1 and SEQ ID NO:14 and a new sequence amplified. After suitable rounds of amplification (approximately 20-30), the overwhelming majority of the sequences contain the mutation. The amplification product with the mutation is ligated into an expression vector and the RNAse with the mutation expressed.

Most commonly, polypeptide sequences are altered by changing the corresponding nucleic acid sequence and expressing the polypeptide. However, polypeptide sequences can also be generated synthetically using commercially available peptide synthesizers to produce any desired polypeptide (*see*, Merrifield, and Stewart & Young, *supra*).

One of skill can select a desired nucleic acid or polypeptide of the invention based upon the sequences provided and upon knowledge in the art regarding ribonucleases generally. The physical characteristics and general properties of RNAses are known to skilled practitioners. The specific effects of some mutations in RNAses are known. Moreover, general knowledge regarding the nature of proteins and nucleic acids allows one of skill to select appropriate sequences with activity similar or equivalent to the nucleic acids and polypeptides disclosed in the sequence listings herein. The definitions section herein describes exemplary conservative amino acid substitutions.

Finally, most modifications to nucleic acids and polypeptides are evaluated by routine screening techniques in suitable assays for the desired characteristic. For instance, changes in the immunological character of a polypeptide can be detected by an appropriate immunological assay. Modifications of other properties such as nucleic acid hybridization to a target nucleic acid, redox or thermal stability of a protein, thermal hysteresis, hydrophobicity, susceptibility to proteolysis, or the tendency to aggregate are all assayed according to standard techniques.

To obtain high level expression of a cloned gene, such as those cDNAs encoding ribonuclease, it is important to construct an expression vector that contains a strong promoter to direct transcription, a transcription/translation terminator, and a ribosome binding site for translational initiation. Suitable bacterial promoters are well

known in the art and described, *e.g.*, in Sambrook *et al.* and Ausubel *et al.* Bacterial expression systems for expressing ribonuclease are available in, *e.g.*, *E. coli, Bacillus sp.*, and *Salmonella* (Palva, *et al.*, *Gene* **22**:229-235 (1983); Mosbach, *et al.*, *Nature* **302**:543-545 (1983). Kits for such expression systems are commercially available. Eukaryotic expression systems for mammalian cells, yeast, and insect cells are well known in the art and are also commercially available.

The promoter used to direct expression of a heterologous nucleic acid depends on the particular application. The promoter is preferably positioned about the same distance from the heterologous transcription start site as it is from the transcription start site in its natural setting. As is known in the art, however, some variation in this distance can be accommodated without loss of promoter function.

In addition to the promoter, the expression vector typically contains a transcription unit or expression cassette that contains all the additional elements required for the expression of the ribonuclease-encoding nucleic acid in host cells. A typical expression cassette thus contains a promoter operably linked to the nucleic acid sequence encoding ribonuclease and signals required for efficient polyadenylation of the transcript, ribosome binding sites, and translation termination. Depending on the expression system, the nucleic acid sequence encoding ribonuclease may be linked to a cleavable signal peptide sequence to promote secretion of the encoded protein by the transformed cell. Such signal peptides would include, among others, the signal peptides from tissue plasminogen activator, insulin, and neuron growth factor, and juvenile hormone esterase of *Heliothis virescens*. Additional elements of the cassette may include enhancers and, if genomic DNA is used as the structural gene, introns with functional splice donor and acceptor sites.

In addition to a promoter sequence, the expression cassette should also contain a transcription termination region downstream of the structural gene to provide for efficient termination. The termination region may be obtained from the same gene as the promoter sequence or may be obtained from different genes.

The particular expression vector used to transport the genetic information into the cell is not particularly critical. Any of the conventional vectors used for expression in eukaryotic or prokaryotic cells may be used. Standard bacterial expression vectors include plasmids such as pBR322 based plasmids, pSKF, pET15b, pET23D, and

fusion expression systems such as GST and LacZ. Epitope tags can also be added to recombinant proteins to provide convenient methods of isolation, *e.g.*, 6-his.

For example, the cDNA of the RNAses of this invention were inserted into pET11d and the pET15b vectors. These vectors comprise, in addition to the expression cassette containing the coding sequence, the T7 promoter, transcription initiator and terminator, the pBR322 ori site, a *bla* coding sequence and a *lacI* operator.

The vectors comprising the nucleic acid sequences encoding the RNAse molecules or the fusion proteins may be expressed in a variety of host cells, including *E. coli,* other bacterial hosts, yeast, and various higher eukaryotic cells such as the COS, CHO and HeLa cells lines and myeloma cell lines. In addition to cells, vectors may be expressed by transgenic animals, preferably sheep, goats and cattle. Typically, in this expression system, the recombinant protein is expressed in the transgenic animal's milk.

The recombinant nucleic acid will be operably linked to appropriate expression control sequences for each host. For *E. coli* this includes a promoter such as the T7, trp, or lambda promoters, a ribosome binding site and preferably a transcription termination signal. For eukaryotic cells, the control sequences will include a promoter and preferably an enhancer derived from immunoglobulin genes, SV40, cytomegalovirus, etc., and a polyadenylation sequence, and may include splice donor and acceptor sequences.

The expression vectors or plasmids of the invention can be transferred into the chosen host cell by well-known methods such as calcium chloride transformation for *E. coli* and calcium phosphate treatment, liposomal fusion or electroporation for mammalian cells. Cells transformed by the plasmids can be selected by resistance to antibiotics conferred by genes contained on the plasmids, such as the amp, gpt, neo and hyg genes.

Once expressed, the RNAse protein can be purified according to standard procedures of the art, including ammonium sulfate precipitation, column chromatography (including affinity chromatography), gel electrophoresis and the like (*see*, generally, R. Scopes, *Protein Purification*, Springer-Verlag, N.Y. (1982), Deutscher, *Methods in Enzymology Vol. 182: Guide to Protein Purification.*, Academic Press, Inc. N.Y. (1990)).

2. Cleaving the RNAse Protein

After translation in the host cell, the RNAse which comprises a signal peptide is cleaved within the bacterial periplasm. Thus, no further manipulation of the protein is required for activity. For proteins with an amino terminal methionine, if a N-terminal glutamine or pyroglutamic acid is desired, the protein is treated with a cleaving agent or a combination of cleaving agents to remove the methionine. By "cleaving the amino terminal methionine" is meant cleaving the amino terminal methionine or amino terminal peptide from the polypeptides of SEQ ID NO:6, 8, 9, 13, 17, 21, 22, 26 and conservative variants thereof. Thus, by "cleaving the amino terminal methionine", a polypeptide of SEQ ID NO:2, 4, 11, 15, 19, 24 or conservative variants thereof is generated, optionally linked via peptide bonds to additional residues at the carboxy or amino terminus.

The cleaving agent may be a proteolytic enzyme such as an exopeptidase or endopeptidase (collectively, "peptidase") or a chemical cleaving agent. Exopeptidases include aminopeptidase M (Pierce, Rockford, IL) which sequentially remove amino acids from the amino-terminus. Cleavage of the amino terminal methionine by exopeptidases may be controlled by modulating the enzyme concentration, temperature, or time under which the cleavage takes place. The resulting mixture may be purified for the desired protein by means well known to those of skill, for example, on the basis of length by electrophoresis. The chemical cleaving agent, cyanogen bromide, is conveniently employed to selectively cleave methionine residues.

The cleaving agent employed to cleave the amino terminal methionine will typically be chosen so as not to break a peptide bond within the polypeptide of SEQ ID NO:2 and 15 or conservative variants thereof. Alternatively, use of a particular cleaving agent may guide the choice of conservative substitutions of the conservative variants of the polypeptides of the present invention. For example, the sequence of the native protein of SEQ ID NO:2 contains a methionine at position 23. As shown in SEQ ID NO:4 and SEQ ID NO:8, this methionine was changed to a leucine to prevent cleavage of the RNAse polypeptide chain with a 1 methionine by CNBr. Similarly, the native protein of SEQ ID NO:15 contains 2 internal methionines, one at position 22 and the other at position 57. As shown in SEQ ID NO:19 and 21, these methionines corresponding to position 22 and 57

in SEQ ID NO:15 were changed to leucines to prevent cleavage of the polypeptide chain when the N-terminal methionine was cleaved from the remainder of the protein.

The polypeptides of this invention may be purified to substantial purity by standard techniques, including selective precipitation with such substances as ammonium sulfate; column chromatography, immunopurification methods, and others. *See*, for instance, R. Scopes, PROTEIN PURIFICATION: PRINCIPLES AND PRACTICE, Springer-Verlag: New York (1982), U.S. Patent No. 4,673,641, Ausubel, and Sambrook.

C. *Purification of RNAse from Bacterial Cultures*

In the case of secreted proteins, the RNAses of this invention can be isolated and purified from the broth in which the expressing bacteria have been grown without having to resort to the cell lysis methods detailed below.

1. Purification of Protein from Bacterial Periplasm

It is anticipated that RNAse expression from *E. coli* may be low and the protein is exported into the periplasm of the bacteria. The periplasmic fraction of the bacteria can be isolated by cold osmotic shock in addition to other methods known to skill in the art (see Ausubel, and Trayer, H.R. & Buckley, III, C.E., *J. Biol. Chem.* **245**(18):4842 (1970)).

To isolate proteins from the periplasm, the bacterial cells are centrifuged to form a pellet. The pellet is resuspended in a buffer containing 20% sucrose. To lyse the cells, the bacteria are centrifuged and the pellet is resuspended in ice-cold 5 mM $MgSO_4$ and kept in an ice bath for approximately 10 minutes. The cell suspension is centrifuged and the supernatant decanted and saved. The proteins present in the supernatant can be separated from the host proteins by standard separation techniques well known to those of skill in the art.

2. Purification of Inclusion Bodies

When recombinant proteins are expressed by the transformed bacteria in large amounts, typically after promoter induction; but expression can be constitutive, the proteins may form insoluble aggregates.

Purification of aggregate proteins (hereinafter referred to as inclusion bodies) involves the extraction, separation and/or purification of inclusion bodies by disruption of bacterial cells, typically but not limited by, incubation in a buffer of about 100-150 μg/mL lysozyme and 0.1% Nonidet P40®, a non-ionic detergent. The cell suspension can be ground using a Polytron® grinder (Brinkman Instruments, Westbury, N.Y.). Alternatively, the cells can be sonicated on ice. Alternate methods of lysing bacteria are described in Ausubel and Sambrook and will be apparent to those of skill in the art.

The cell suspension is centrifuged and the pellet containing the inclusion bodies resuspended in buffer, *e.g.*, 20 mM Tris-HCl (pH 7.2), 1 mM EDTA, 150 mM NaCl and 2% Triton-X 100®, a non-ionic detergent. It may be necessary to repeat the wash step to remove as much cellular debris as possible. The remaining pellet of inclusion bodies may be resuspended in an appropriate buffer (e.g. 20 mM sodium phosphate, pH 6.8, 150 mM NaCl). Other appropriate buffers will be apparent to those of skill in the art.

Following the washing step, the inclusion bodies are solubilized by the addition of a solvent that is both a strong hydrogen acceptor and a strong hydrogen donor (or a combination of solvents each having one of these properties); the proteins that formed the inclusion bodies may then be renatured by dilution or dialysis with a compatible buffer. Suitable solvents include, but are not limited to urea (from about 4 M to about 8 M), formamide (at least about 80%, volume/volume basis), and guanidine hydrochloride (from about 4 M to about 8 M). Some solvents which are capable of solubilizing aggregate-forming proteins, for example SDS (sodium dodecyl sulfate), 70% formic acid, are inappropriate for use in this procedure due to the possibility of irreversible denaturation of the proteins, accompanied by a lack of immunogenicity and/or activity. Although guanidine hydrochloride and similar agents are denaturants, this denaturation is not irreversible and renaturation may occur upon removal (by dialysis, for example) or dilution of the denaturant, allowing re-formation of immunologically and/or biologically active protein.

After solubilization, the protein can be separated from other bacterial proteins by standard separation techniques.

D. *Standard Protein Separation Techniques*

1. Solubility Fractionation

Often as an initial step and if the protein mixture is complex, an initial salt fractionation can separate many of the unwanted host cell proteins (or proteins derived from the cell culture media) from the recombinant protein of interest. The preferred salt is ammonium sulfate. Ammonium sulfate precipitates proteins by effectively reducing the amount of water in the protein mixture. Proteins then precipitate on the basis of their solubility. The more hydrophobic a protein is, the more likely it is to precipitate at lower ammonium sulfate concentrations. A typical protocol is to add saturated ammonium sulfate to a protein solution so that the resultant ammonium sulfate concentration is between 20-30%. This will precipitate the most hydrophobic of proteins. The precipitate is discarded (unless the protein of interest is hydrophobic) and ammonium sulfate is added to the supernatant to a concentration known to precipitate the protein of interest. The precipitate is then solubilized in buffer and the excess salt removed if necessary, either through dialysis or diafiltration. Other methods that rely on solubility of proteins, such as cold ethanol precipitation, are well known to those of skill in the art and can be used to fractionate complex protein mixtures.

2. Size Differential Filtration

If the size of the protein of interest is known or can be estimated from the cDNA sequence, proteins of greater and lesser size can be removed by ultrafiltration through membranes of different pore size (for example, Amicon or Millipore membranes). As a first step, the protein mixture is ultrafiltered through a membrane with a pore size that has a lower molecular weight cut-off than the molecular weight of the protein of interest. The retentate of the ultrafiltration is then ultrafiltered against a membrane with a molecular cut off greater than the molecular weight of the protein of interest. The recombinant protein will pass through the membrane into the filtrate. The filtrate can then be chromatographed as described below.

3. Column Chromatography

Proteins can be separated on the basis of their size, net surface charge, hydrophobicity and affinity for ligands. In addition, antibodies raised against proteins can be conjugated to column matrices and the proteins immunopurified. All of these methods are well known in the art.

It will be apparent to one of skill that chromatographic techniques can be performed at any scale and using equipment from many different manufacturers (*e.g.*, Pharmacia Biotech).

In a preferred embodiment of this invention, the proteins are expressed from *E. coli* with a six histidine residue tag joined via a peptide bond to a 7 methionine. After the protein is purified to homogeneity as in Newton, *et al., Biochemistry* **35**:545 (1996), the protein is cleaved at the 7 methionine as described above. The CNBr is removed and the mixture applied to a Ni^{2+}-NTA agarose column. The flow-through material is the cleaved product of interest.

E. *Cyclization*

Upon cleavage of the N-terminal methionine and other residues of the amino terminal peptide, a protein comprising the polypeptide of SEQ ID NO:2 or 15 or a conservatively modified variant thereof is generated. The glutamine residue of SEQ ID NO:2 or 15 is caused to cyclize by any number of means, including spontaneously or by catalysis, to a pyroglutamyl residue. Spontaneous hydrolysis of amino terminal glutamine residues to their pyroglutamyl form is well known to the skilled artisan and its rate may be hastened by, for example, increasing the temperature. *See, e.g.,* Robinson, *et al., J. Am. Chem. Soc.* **95**:8156-8159 (1973). Cytotoxicity or anti-viral activity of the resultant RNAse protein may be assessed by means herein disclosed and well known to the skilled artisan.

VII. Ligand Binding Moieties

The polypeptides and proteins of the present invention may also be joined via covalent or non-covalent bond to a ligand binding moiety. The RNAse molecule may be joined at the amino or carboxy terminus to the ligand or may also be joined at an internal region as long as the attachment does not interfere with the respective activities of

the molecules. Immunoglobulins or binding fragments thereof (*e.g.*, single-chain Fv fragments) may conveniently be joined to the polypeptides of the present invention. Vaughan, *et al., Nature Biotechnology* **14**:309-314 (1996).

A. *Chemically Conjugated Fusion Proteins*

In one embodiment, the RNAse molecule is chemically conjugated to another molecule (*e.g.* a cytotoxin, a label, a ligand, or a drug or liposome). Means of chemically conjugating molecules are well-known to those of skill.

The procedure for attaching an agent to an antibody or other polypeptide targeting molecule will vary according to the chemical structure of the agent. Polypeptides typically contain a variety of functional groups; *e.g.*, carboxylic acid (COOH) or free amine ($-NH_2$) groups, which are available for reaction with a suitable functional group on an RNAse molecule to bind the other molecule thereto.

Alternatively, the ligand and/or RNAse molecule may be derivatized to expose or attach additional reactive functional groups. The derivatization may involve attachment of any of a number of linker molecules such as those available from Pierce Chemical Company, Rockford Illinois.

A "linker", as used herein, is a molecule that is used to join two molecules. The linker is capable of forming covalent bonds to both molecules. Suitable linkers are well known to those of skill in the art and include, but are not limited to, straight or branched-chain carbon linkers, heterocyclic carbon linkers, or peptide linkers. Where both molecules are polypeptides, the linkers may be joined to the constituent amino acids through their side groups (*e.g.*, through a disulfide linkage to cysteine). However, in a preferred embodiment, the linkers will be joined to the alpha carbon amino and carboxyl groups of the terminal amino acids.

A bifunctional linker having one functional group reactive with a group on a particular agent, and another group reactive with an antibody, may be used to form a desired immunoconjugate. Alternatively, derivatization may involve chemical treatment of the ligand, *e.g.*, glycol cleavage of the sugar moiety of a glycoprotein antibody with periodate to generate free aldehyde groups. The free aldehyde groups on the antibody may be reacted with free amine or hydrazine groups on an agent to bind the agent thereto. (See U.S. Patent No. 4,671,958). Procedures for generation of free sulfhydryl groups on

polypeptides, such as antibodies or antibody fragments, are also known (See U.S. Pat. No. 4,659,839).

Many procedure and linker molecules for attachment of various compounds including radionuclide metal chelates, toxins and drugs to proteins such as antibodies are known. See, for example, European Patent Application No. 188,256; U.S. Patent Nos. 4,671,958, 4,659,839, 4,414,148, 4,699,784; 4,680,338; 4,569,789; and 4,589,071; and Borlinghaus, *et al. Cancer Res.* 47:4071-4075 (1987) which are incorporated herein by reference. In particular, production of various immunotoxins is well-known within the art and can be found, for example in "Monoclonal Antibody-Toxin Conjugates: Aiming the Magic Bullet," Thorpe, *et al.*, MONOCLONAL ANTIBODIES IN CLINICAL MEDICINE, Academic Press, pp. 168-190 (1982), Waldmann, *Science* **252**:1657 (1991), U.S. Patent Nos. 4,545,985 and 4,894,443.

In some circumstances, it is desirable to free the RNAse from the ligand when the chimeric molecule has reached its target site. Therefore, chimeric conjugates comprising linkages which are cleavable in the vicinity of the target site may be used when the effector is to be released at the target site. Cleaving of the linkage to release the agent from the ligand may be prompted by enzymatic activity or conditions to which the immunoconjugate is subjected either inside the target cell or in the vicinity of the target site. When the target site is a tumor, a linker which is cleavable under conditions present at the tumor site (*e.g.* when exposed to tumor-associated enzymes or acidic pH) may be used.

A number of different cleavable linkers are known to those of skill in the art. See U.S. Pat. Nos. 4,618,492; 4,542,225, and 4,625,014. The mechanisms for release of an agent from these linker groups include, for example, irradiation of a photolabile bond and acid-catalyzed hydrolysis. U.S. Pat. No. 4,671,958, for example, includes a description of immunoconjugates comprising linkers which are cleaved at the target site *in vivo* by the proteolytic enzymes of the patient's complement system. In view of the large number of methods that have been reported for attaching a variety of radiodiagnostic compounds, radiotherapeutic compounds, drugs, toxins, and other agents to antibodies one skilled in the art will be able to determine a suitable method for attaching a given agent to an antibody or other polypeptide.

B. *Recombinant Fusion Proteins*

In a preferred embodiment, the chimeric fusion proteins of the present invention are synthesized using recombinant DNA methodology. Generally this involves creating a DNA sequence that encodes the fusion protein, placing the DNA in an expression cassette under the control of a particular promoter, expressing the protein in a host, isolating the expressed protein and, if required, renaturing the protein.

In one embodiment, the ribonucleases of the invention are fused in frame to single chain antibodies. For tumor cell killing, the antibodies typically specifically bind to a target on the tumor cell. In other embodiment, the fusion proteins comprise a ligand which binds to a receptor on a tumor cell. For example, hCG binds and is cytotoxic to Kaposi's Sarcoma cells. By making a fusion protein comprising hCG and the ribonucleases of this invention, a compound that binds to the tumor cells and is more cytotoxic than hCG alone can be achieved.

DNA encoding the fusion proteins of this invention, as well as the recombinant RNAse molecules themselves, may be prepared by any suitable method, including, for example, cloning and restriction of appropriate sequences or direct chemical synthesis by methods such as the phosphotriester method of Narang, *et al. Meth. Enzymol.* **68**:90-99 (1979); the phosphodiester method of Brown, *et al., Meth. Enzymol.* **68**:109-151 (1979); the diethylphosphoramidite method of Beaucage, *et al., Tetra. Lett.* **22**:1859-1862 (1981); and the solid support method of U.S. Patent No. 4,458,066.

In a preferred embodiment, DNA encoding fusion proteins or recombinant RNAse proteins of the present invention may be cloned using DNA amplification methods such as polymerase chain reaction (PCR). If two molecules are joined together, one of skill will appreciate that the molecules may be separated by a peptide spacer consisting of one or more amino acids. Generally the spacer will have no specific biological activity other than to join the proteins or to preserve some minimum distance or other spatial relationship between them. However, the constituent amino acids of the spacer may be selected to influence some property of the molecule such as the folding, net charge, or hydrophobicity.

The nucleic acid sequences encoding the recombinant RNAse molecules or the fusion proteins may be expressed in a variety of host cells, including *E. coli,* other bacterial hosts, yeast, and various higher eukaryotic cells such as the COS, CHO and HeLa

cell lines and myeloma cell lines. The recombinant protein gene will be operably linked to appropriate expression control sequences for each host. For *E. coli,* this includes a promoter such as the T7, trp, or lambda promoters, a ribosome binding site and preferably a transcription termination signal. For eukaryotic cells, the control sequences will include a promoter and preferably an enhancer derived from immunoglobulin genes, SV40, cytomegalovirus, *etc.*, and a polyadenylation sequence, and may also include splice donor and acceptor sequences.

The expression vectors or plasmids of the invention can be transferred into the chosen host cell by well-known methods such as calcium chloride transformation for *E. coli* and calcium phosphate treatment or electroporation for mammalian cells. Cells transformed by the plasmids can be selected by resistance to antibiotics conferred by genes contained on the plasmids, such as the *amp*, *gpt*, *neo* and *hyg* genes.

Once expressed, the recombinant RNAse or fusion proteins can be purified according to standard procedures of the art, as described above, including ammonium sulfate precipitation, affinity columns, column chromatography, gel electrophoresis and the like (*see*, generally, R. Scopes, PROTEIN PURIFICATION, Springer-Verlag, N.Y. (1982), Deutscher, METHODS IN ENZYMOLOGY VOL. 182: *Guide to Protein Purification.*, Academic Press, Inc. N.Y. (1990)). Substantially pure compositions of at least about 90 to 95% homogeneity are preferred, and 98 to 99% or more homogeneity are most preferred for pharmaceutical uses. Once purified, partially or to homogeneity as desired, the polypeptides may then be used therapeutically.

VIII. Uses of RNAse

The molecules of this invention, both the fusion proteins and RNAse alone can be used for a variety of uses.

A. *Anti-Tumor Drug*

The RNAse molecules are uniquely adapted for gene therapy applications. They can be fused to other therapeutic agents, for example, they could be fused to an anti-B cell lymphoma antibody, an anti-transferrin receptor antibody or an anti-colon cancer antibody. As mentioned above, native Onconase® has anti-tumor effects *in vivo* and preferentially kills rapidly dividing cells stimulated by serum or growth promoting agents

such as ras. The RNAses of this invention can be used in a similar manner. The RNAses of this invention are readily internalized in the cell. Their activity can be further facilitated by joining them to a nuclear localization signal (NLS) and the like to redirect the molecules within the cell. Of particular use in tumor cells would be to target telomerase, an enzyme subject to degradation by ribonuclease.

Telomerase is being investigated as a "universal cancer target." It is an RNA protein that is located in the nucleus. It has been shown that antisense to telomerase RNA can inhibit the function of the enzyme and block the growth of cancer cells (Feng, *et al.*, *Science* **269**:1236 (1995)). Previous studies have shown RNase can destroy the activity of the enzyme when incubated with a cell extract containing telomerase. Thus a RNAse molecule can be made, which when administered to a person with cancer, would be routed to the nucleus of cells.

In a gene therapy protocol, a vector containing an expression cassette which encodes for the RNAses of this invention can be used either to infect cells *ex vivo*, for example hematopoietic cells in lymphoma or leukemia, or to infect cells *in vitro*. Recently, there has been a lot of activity in synthesizing retroviral vectors with chimeric coat proteins. The chimeric proteins typically comprise two domains, one of which is embedded in the viral coat and is of retroviral origin. The second domain is heterologous to the virus and is a member of a binding pair. For example, the second domain consists of a single chain Fv fragment which binds to a tumor cell surface marker or it is the ligand to which an antibody expressed on the cell surface binds. Other binding pairs, not necessarily monoclonal antibodies and their ligands will be apparent to those of skill.

Studies with Onconase® have indicated other potential uses. It has been found that Onconase® synergizes with ras in microinjection studies. Onconase® does not synergize with ras when it enters the cell via its own routing but requires a CAAX motif to localize ras at the plasma membrane (C=Cys, A = an aliphatic amino acid, X = S,M,C,A, or Q, an example is Cys-Val-Ile-Met (SEQ ID NO:29)). Importantly this type of sequence has been shown to target heterologous proteins to the plasma membrane (Hancock, J., *et al.*, *EMBO J.* **10**:4033 (1991)). The RNAses of this invention have identical uses.

B. *Targeted Fusion Proteins*

The RNAses of this invention can be joined to a ligand binding moiety that is specific for tumor cells. Examples of such ligand binding moieties include, but are not limited to, monoclonal antibodies directed against tumor cell markers such as heregulin, CD22, PSA, *etc.*; cytokines that target tumor cells, such as tumor necrosis factor; and other tumor cell binding proteins, including hCG.

In addition, one of skill will recognize that two cytotoxic factors can be joined to one ligand binding moiety. For example, the RNAses of this invention can be joined to a monoclonal antibody directed against a tumor cell marker which is also joined to a synthetic drug with cytotoxic activity, such as paclitaxel or methotrexate.

Finally, the fusion proteins of this invention find use as cytotoxic agents against cells other than tumor cells. For example, the RNAses of this invention are joined to ligand binding moieties that specifically target B cells which secrete antibodies directed against self. Thus, the RNAses of this invention are useful in the treatment of autoimmune diseases.

IX. Pharmaceutical Compositions

The molecules and fusion proteins employing them of this invention are useful for parenteral, topical, oral, or local administration, such as by aerosol or transdermally, for prophylactic and/or therapeutic treatment. The pharmaceutical compositions can be administered in a variety of unit dosage forms depending upon the method of administration. For example, unit dosage forms suitable for oral administration include powder, tablets, pills, capsules and lozenges. It is recognized that the subject molecules and fusion proteins and pharmaceutical compositions of this invention, when administered orally, must be protected from digestion. This is typically accomplished either by complexing the protein with a composition to render it resistant to acidic and enzymatic hydrolysis or by packaging the protein in an appropriately resistant carrier such as a liposome. Means of protecting proteins from digestion are well known in the art.

The pharmaceutical compositions of this invention are particularly useful for parenteral administration, such as intravenous administration or administration into a body cavity or lumen of an organ. The compositions for administration will commonly comprise a solution of the chimeric molecule dissolved in a pharmaceutically acceptable

carrier, preferably an aqueous carrier. A variety of aqueous carriers can be used, *e.g.*, buffered saline and the like. These solutions are sterile and generally free of undesirable matter. These compositions may be sterilized by conventional, well known sterilization techniques. The compositions may contain pharmaceutically acceptable auxiliary substances as required to approximate physiological conditions such as pH adjusting and buffering agents, toxicity adjusting agents and the like, for example, sodium acetate, sodium chloride, potassium chloride, calcium chloride, sodium lactate and the like. The concentration of therapeutic molecule in these formulations can vary widely, and will be selected primarily based on fluid volumes, viscosities, body weight and the like in accordance with the particular mode of administration selected and the patient's needs.

Thus, a typical pharmaceutical composition for intravenous administration would be about 0.1 mg to 10 mg per patient per day. Dosages from 0.1 mg up to about 100 mg per patient per day may be used, particularly when the drug is administered to a secluded site and not into the blood stream, such as into a body cavity or into a lumen of an organ. Actual methods for preparing parenterally administrable compositions will be known or apparent to those skilled in the art and are described in more detail in such publications as REMINGTON'S PHARMACEUTICAL SCIENCE, 15th ed., Mack Publishing Company, Easton, Pennsylvania (1980).

The compositions containing the present recombinant RNAse molecules or the fusion proteins or a cocktail thereof (*i.e.*, with other proteins) can be administered for therapeutic treatments. In therapeutic applications, compositions are administered to a patient suffering from a disease, in a cytotoxic amount, an amount sufficient to kill cells of interest. An amount adequate to accomplish this is defined as a "therapeutically effective dose." Amounts effective for this use will depend upon the severity of the disease and the general state of the patient's health.

Single or multiple administrations of the compositions may be administered depending on the dosage and frequency as required and tolerated by the patient. In any event, the composition should provide a sufficient quantity of the proteins of this invention to effectively treat the patient.

Although the present invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be obvious that

certain changes and modifications may be practiced within the scope of the appended claims.

X. Examples

A. *Example 1: Expression Pattern of RNAse in Rana pipiens Tissues*

A DNA sequence corresponding to amino acid residues 16-98 of Onconase® was cloned by PCR amplification of *Rana pipiens* genomic DNA and sequenced. The sequence, consisting of 252 bp of DNA encoding the ribonuclease was designated *Rana* clone 9. Total cellular RNA was isolated from either male or female *Rana pipiens* tissues using RNA STAT-60 (TEL-TEST "B", Inc.) according to the manufacturer's protocol. Poly A+ containing mRNA was prepared using an Oligotex mRNA kit (Qiagen). Poly (A+) RNA was size fractionated on a 1% agarose gel containing 6% formaldehyde and blotted onto Nitran® nylon membranes (Schleicher & Schuell) in 10X SSC overnight. The membrane was rinsed in 2X SSC for 5 min, air dried and the RNA was cross linked to the membrane by exposure to UV light (Ultra-Lum) for 2 min. The RNA blot was hybridized at 42°C for 16-18 hours with a [^{32}P]-labeled DNA probe prepared from 30 ng of *Rana* clone 9 insert using the oligo labeling kit from Amersham. After hybridization, the RNA blot was washed twice in 1X SSC, 1% SDS for 20 min at 42°C. The blot was exposed to X-ray film for 4 days. The molecular size of mRNA was estimated using 0.24-9.5 kb RNA molecular weight markers (BRL).

Since Onconase® is isolated in large quantities from the oocytes of *Rana pipiens*, it was assumed that high levels of RNAse RNA would be present in the mRNA from oocytes. Surprisingly, mRNA reacting with *Rana* clone 9 was not detected in *Rana pipiens* oocyte, heart, lung and kidney tissues. The only mRNA signal detected with *Rana* clone 9 was a strongly hybridizing 3.6 kb RNA in mRNA isolated from *Rana pipiens* liver. As a protocol control, the same northern blot was probed with a [^{32}P]-labeled human actin cDNA. Actin mRNA was detectable in all of the tissues. In another northern analysis with four-fold more liver poly (A+) mRNA, a second weakly hybridizing mRNA of about 950 bp was detected.

To confirm that RNAse mRNA was present in *Rana pipiens* liver but not in oocytes, RT-PCR was performed using total RNA isolated from *Rana pipiens* liver and oocytes and with the degenerate primers used in the cloning of the *Rana* clone 9 insert.

Total RNA was isolated from *Rana pipiens* liver and oocytes. The procedure of Chen, *et al., Oncogene* **12**:741 (1996) was used. Briefly, PCR was carried out under the following conditions: 94°C for 5 minutes and then 30 cycles of denaturation at 94°C for 1 min, annealing for 2 min at 55°C, and primer extension for 1 min at 72°C. The degenerate forward primer used [(5'-AG(GA)GATGT(GT)GATTG(TC)GATAA(CT)ATCATG-3' (SEQ ID NO:30)] with the reverse degenerate primer [5'-AAA(GA)TG(CA)AC(AT)GG(TG)GCCTG(GA)TT(CT)TCACA-3' (SEQ ID NO:31)].

The PCR products were analyzed on a 1.5% agarose gel and stained with ethidium bromide. the PCR product obtained from liver was subcloned into PCR3 vector by TA cloning (Invitrogen) and sequenced.

A band of the expected size of about 250 bp was generated in the liver RNA but not oocyte RNA, consistent with the result from northern blot analysis. To ensure that the 250 bp band represented RNAse cDNA, this PCR product was subcloned and its DNA sequence determined with the Sequenase v. 2.0 kit (United States Biochemical).

Bases 1, 7, 13, 23 and 235 of the PCR product differed from the sequence of *Rana* clone 9. With the exception of the change at base 23, all of the other base changes were within the degenerate primer sequences. The difference at base 23 is an A to T transition which results in conservative amino acid change from threonine to serine, and could be due to polymorphism of the RNAse gene or a PCR error.

B. *Example 2: Expression of RNAse in Rana pipiens*

To determine if RNAse is present in *Rana pipiens* oocytes or other tissues, protein extracts were isolated from various *Rana pipiens* tissues and separated on a 4-20% Tris-Glycine SDS- containing polyacrylamide gel. The protein extracts were transferred to a nitrocellulose membrane using 1X transfer buffer (Novagen) at 250 mA for 45 min. The membrane was probed with primary and secondary antibodies as described in Chen, *et al., Oncogene* **12**:241 (1996). The primary anti-Onconase® antibody was used at 1:100 dilution. The detecting antibody (horseradish peroxidase labeled donkey anti-rabbit Ig (Amersham)) was used at 1:2500 dilution. The antibodies were visualized using an ECL detection kit from Amersham.

The western blot analysis demonstrated that a protein of the correct size (12 kDa) was present in extracts from oocytes. Other tissues, including liver, did not contain a 12 kDa protein that reacted with the anti-Onconase® antibody. High molecular weight bands were also observed. These represented other forms of Onconase® (*e.g.*, glycosylated or multimeric) or represented related members of the pancreatic ribonuclease A amphibian superfamily. It had been previously determined that the anti-Onconase® antibody cross reacts with other pancreatic type RNAses such as bovine pancreatic ribonuclease as well as two human RNAses; eosinophil-derived neurotoxin and angiogenin.

C. *Example 3: Isolation and cloning of cDNA from Rana pipiens liver mRNA*

Liver poly (A+) RNA was purified twice using the poly (A+) Pure kit (Ambion). The cDNA library was constructed using a ZAP-cDNA synthesis kit and Gigapack II gold packaging extracts according to the manufacturer's protocol (Stratagene). The library contained about 1.5 x 10^6 pfu from 5 μg of liver poly (A+) RNA and was amplified once according to Stratagene's protocol. The library titer after amplification was 9 x 10^9 pfu/mL. About 3 x 10^5 plaques were screened by using a [^{32}P]-labeled insert of *Rana* clone 9 following Stratagene's procedure. Positive clones (3a1b, 4a1b and 5a1b) were excised from the lambda ZAP II vector and subcloned into pBluescript SF- vector. Plasmid DNA was prepared using the Qiagen spin plasmid miniprep kit.

Clone 5a1b was digested with *Kpn*I and *Hind*III to generate 3' and 5' protruding ends, and digested with exonuclease III to generate 5a1b deletion clones. Overlapping deletions were generated according to the manufacturer's instructions with the Erase-a-Base system (Promega). The size of DNA inserts from the deletion clones were estimated from agarose gel analysis, and the selected clones were sequenced using the T7 promoter primer. The cDNA of clone 4a1b, the 5' end of clone 3a1b and part of the clone 5a1b were sequenced using T3, T7 and appropriate primers. All the sequencing reactions were performed using the Sequenase v. 2.0 kit (United States Biochemical) and α-[35S] dATP (>1000 Ci/mmole, Amersham). Both strands of clone 5a1b were sequenced.

Clone 5a1b cDNA (SEQ ID NO:27) which was about 2.8 kb in size, contained an open reading frame (ORF) at the 5' end. The deduced amino acids at positions 1-23 were characteristic of a signal peptide with a charged amino acid within the

first 5 amino acids, a stretch of at least 9 hydrophobic amino acids to span the membrane, and a cysteine at position 23. The putative signal peptide sequence was followed by a highly conserved but not identical amino acid sequence compared to Onconase®. There were four amino acid differences between the ORF of clone 5a1b and Onconase® including amino acid residues 11, 20, 85 and 103. With the exception of a conservative change at amino acid residue 11, all the other amino acid conversions are between polar and charged amino acid residues.

D. *Example 4: Cloning and Expression of RaPLR1*

Oligonucleotide primers were designed to clone the cDNA sequence of *Rana pipiens* liver RNAse (RaPLR1) as a [met-1] fusion protein as well as to modify the primary amino acid structure by changing the N-terminal amino acid residue following the initiating methionine from glutamine to serine ([Met-(-1)]RaPLR1(Q1S). Thus, the recombinant RNAses obtained from the bacteria in this expression system contain an extra methionine at the amino terminal end [Met-(-1)].

Amplification of these sequences was carried out in a thermal cycler and the DNA was cloned into an expression vector using methodology previously described in Newton, *et al.*, . The plasmids were expressed in Bl21(DE3) *E. coli* and the recombinant proteins were isolated from inclusion bodies as described (Newton, *et al., supra*) before being applied to a CM Sephadex C-50 column. Final purification to homogeneity as assessed by gel electrophoresis was achieved by size exclusion chromatography.

E. *Example 5: Assembly of Synthetic RaCOR1 Gene*

The following oligonucleotides were synthesized:

5'-CAGAACTGGGCTACTTTCCAGFCAGAAACATATCATCAACACTCCGATCATCT G CAACACTATCATGGACAACAACATCTACATCGTTGGTGGTCAG-3' (SEQ ID NO:32)

5'-TACATCGTTGGTGGTCAGTGCAAACGTGTTAACACTTTCATCATCTCTCTGCTA CTACTGTTAAACGTATCTGCACTGGTGTTATC-3 (SEQ ID NO:33)

5'-ATCTGCACTGGTGTTACTAACATGAACGTTCTGTCTACTACTCGTTTCCAGCTG AACACTTGCACTCGTACTTCTATCACTCCGCGTCCGTGCCCG-3 (SEQ ID NO:34)

5'-GTTGATAACACCAGTGCAGAT-3' (SEQ ID NO:35)

5'-ATCTGCACTGGTGTTATCAAC-3' (SEQ ID NO:36)

5'-ACTCCGCGTCCGTGCCCGTACTCTTCTCGTACTGAAACTAACTACATCTGCGTT AAATGCGAAAACCAGTACCCGGTTCATTTCGCTGGTATCGG-3' (SEQ ID NO:37)

5'-ATATATCTAGAAATAATTTTATTTAACTTTAAGAAGGAGATATACATATGCAG A ACTGGGCTACTTTCCAG-3' (SEQ ID NO:38)

5'-CGCGCCGGATCCCTACTACGGGCAACGACCGATACCAGCGAAATGAAC-3' (SEQ ID NO:39)

5'-CAGAACTGGGCTACTTTCCAGCAGAAACATATCATCAACACTCCGATCATCTG CAACACTATCCTGCAGAACAACATCTACATCGTTGGTGGTCAG-3' (SEQ ID NO:40)

5'-ATCTGCACTGGTGTTATCAACCTGAACGTTCTGTCTACTACTCGTTTCCAGCTG AACACTTGCACTCGTACTTCTATCACTCCGCGTCCGTGCCCG-3' (SEQ ID NO:41)

PCR reactions were performed containing:

1X reaction buffer (100 mM Tris-HCl, pH 8.3, 500 mM KCl, 1.5 mM $MgCl_2$);

0.4 mM nucleotides;

5.0 units Amplitaq® DNA polymerase;

0.5 μM oligonucleotides (SEQ ID NO:32-41) in the combinations listed below; and water to adjust to 100 μL final volume.

The thermal cycler conditions were as follows: 94°C for 5 min preincubation then 20 cycles at 94°C for 1 min; 55° for 2 min; and 72°C for 2 min. The first PCR reaction contained SEQ ID NO:32, 33 and 35, which comprised the 5' half of the RNAse gene.

The second PCR reaction contained SEQ ID NO:34, 36, and 37 which comprised the 3' half of the gene. For the proteins wherein positions corresponding to positions 22 and 57 of SEQ ID NO:15 were changed to leucines, the first reaction was with SEQ ID NO:33, 35 and 38 to synthesize the 5' half of the gene and the second was with SEQ ID NO:36, 37 and 38 to synthesize the 3' half of the gene.

The PCR products were purified using the Geneclean® II kit from Bio 101, Inc. Vista, CA) according to the manufacturer's instructions. The following PCR reactions were performed under conditions as above to assemble the complete gene as shown in Figure 1. To assemble the non-mutated gene, SEQ ID NO:38 and 39 were added to the purified PCR products. To assemble the gene with the methionine to leucine mutation, SEQ ID NO:40 and 41 were used.

The assembled genes were purified by the GeneClean® procedure, cleaved with the endonucleases *Xba*I and *BamH*I overnight and ligated into the pET-11d vector. The DNA was sequences, expressed and the protein purified as described in Newton, *et al., Biochemistry* **35**:545 (1996). The nucleotide sequence of the non-mutated synthetic gene is shown in SEQ ID NO:14. The amino acid sequence of the gene product is as shown in SEQ ID NO:15.

The clone containing the mutations was subsequently modified by PCR to insert an *Nde*I restriction site for ligation into the pET-15b vector (which encodes a six histidine tag as well as a thrombin cleavage site at the 5' end of the expression cassette insertion point) by using primers as shown in SEQ ID NO:39 and 5'-GGATTCCATATGCAGAACTGGGCTATTTTCCAG-3' (SEQ ID NO:42). The PCR methods were as shown above.

F. *Example 6: Purification of RNAse with Mutations*

The purified *Rana catesbeiana* proteins of Example 5 contained a six histidine tail at the N-terminus. The protein was treated with CNBr as described by Gross & Witkop, *J. Biol. Chem.* **237**:1856 (1962). In brief, the protein (dissolved in 0.1 N HCl) was treated with 100-fold molar excess of CNBr for 24 hours at ambient temperature. CNBr cleaves on the carboxyl side of methionine residues; the mutated protein contains only one methionine at the 1 position. The CNBr was removed by lyophilization and the protein dissolved in 0.1 M Tris-HCl, pH 7.5. The soluble protein was applied to a Ni^{2+}-

NTA agarose column (Qiagen) to remove the uncleaved protein from the +1 Gln cleaved protein. The His tail bound to the Ni^{2+}-NTA column and the cleaved RNAse was found in the flow-through. Elution of the column yielded the His-containing cleavage product and non-cleaved $(His)_6$ (SEQ ID NO:43) containing protein. Densitometry analysis of cleaved and non-cleaved protein demonstrated that 50% of the protein was cleaved by CNBr.

The mutated protein was allowed to cyclize at the N-terminus to form pyroglutamic acid by dialysis in 0.2 M KPO_4 buffer. An amino end group analysis was performed to ensure the presence of a blocked NH_2-terminus.

G. *Example 7: Analysis of RNAse Activity*

The methods used to assay the recombinant RNAses of this invention were done as described in Newton, *et al., Protein Engineering* **10**:463 (1997). Briefly, ribonuclease activity using high molecular weight RNA and tRNA was determined at 37°C by monitoring the formation of perchloric acid-soluble nucleotides. The buffer was 0.16 M Tris-HCl, pH 7.5 with 1.6 mM EDTA and 0.2 mg/mL human serum albumin (HSA). Ribonuclease activity was assayed according to DePrisco, *et al., Biochemica et Biophysica Acta* **788**:356 (1984) and Libonati & Floridi, *Eur. J. Biochem.* **8**:81 (1969) by measuring the increase with time in absorbance at 260 nm. Incubation mixtures (1 mL of 10 mM imidazole, 0.1 M NaCl, pH 7.0) contained substrate and appropriate amounts of enzyme solution at 25°C. Final substrate concentration in the assays was 0.33 mg/mL tRNA. Each assay was repeated 2-6 times and the average value was used in data treatment. Kinetic parameters were obtained with the aid of the data analysis program of Cleland, *Methods of Enzymol.* **63**:103 (1979).

The results of the assay is shown in Table I.

Table I. Ribonuclease Activity

RNAse	RNAse Activity (units/mg protein)	Fold Increase
native Onconase®	9	
recombinant *Rana catesbeiana* RNAse	200	22
recombinant Onconase® (Q1S)	1.5	
recombinant *Rana pipiens* RNAse (Q1S)	2.5	1.7

The cytotoxicity of the RNAses of this invention was determined by measuring the protein synthesis of tumor cells in the presence of the RNAse. Protein synthesis was measured as previously described in Rybak, *et al., J. Biol. Chem.* **266**:21202 (1991). 0.1 mL of cells (2.5 x. 10^4 cells/mL) were plated into 96-well microtiter plates in Dulbecco's Minimum Essential Medium supplement with 10% heat-inactivated fetal bovine serum (Δ-FBS); additions were made in a total volume of 10 μL; and the plates were incubated at 37°C for the times indicated. Phosphate-buffered saline (PBS) containing 0.1 mCi of [^{14}C]-leucine was added for 2-4 hours, and the cells were harvested onto glass fiber filters using a PHD cell harvester, washed with water, dried with ethanol and counted in a scintillation counter. The results are expressed in Table II as percent of [^{14}C]-leucine incorporation in the mock-treated wells.

Recombinant Onconase® with a methionine at the 1 position was not very cytotoxic since correct hydrogen bonding at the active site is fostered by the pyroglutamic acid N-terminus of the native protein (Newton, *et al., Protein Engineering* **10**:463 (1997)). In the four human tumor cell lines tested, the recombinant *Rana pipiens* liver RNAses were more active than recombinant Onconase®. It appears that the four amino acid differences in RaPLR1 change the active site configuration such that is does not display the degree of dependence Onconase® has on the N-terminal pyroglutamic acid residue for correct hydrogen bonding at the active site.

Similarly, RaCOR1 was also more cytotoxic than recombinant Onconase®. Again, most likely this is due to an active site that is not dependent on the N-terminal pyroglutamic acid for correct hydrogen bonding.

Table II Cytotoxicity in human tumor cells of recombinant RNAses (IC_{50} (nM))

Cell Line	Tumor type	rec Onconase®	rec RaPLR1	**Fold Increase**	rec RAPLR Q1S	**Fold Increase**	rec RACOR	**Fold Increase**
SF539	Glioma	29,200	2,300	**13**	417	**70**	1,300	**22**
HS578T	Breast	>8,300	8,300	**>1**	670	**>8**	2,500	**>3**
ACHN	Kidney	26,700	3,300	**8**	1,580	**17**	1,000	**11**
Malme	Melanoma	25,000	580	**43**	750	**33**	1,000	**25**
MCF7	Breast	>8,300					320	**26**

It is understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims. All publications, patents, and patent applications cited herein are hereby incorporated by reference for all purposes.